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## DESIGN PARAMETERS OF HARDENING DIFFUSERS UNDER A CRITICAL AIR FLOW

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A generalization of the design and technological parameters of cooling diffusers under a critical air flow from the nozzles in hardening glass of various thickness is proposed.

Sheet glass hardening technology proposes using the effect of critical air flow from the chilling diffuser nozzles. The method for calculating the cooling capacity of air jets [1] in such conditions is inefficient; therefore, the present study attempts to generalize data on the design and technological parameters of diffusers and to identify their limiting capabilities.

We have previously [2] introduced the concept of guaranteed coefficient of heat transfer from the surface of a heated glass sheet to the cooling agent  $a_g$  and have determined a relationship for its calculation, which in the IS system takes the following form:

$$a_g = \frac{1.703}{d},$$

where  $d$  is the glass thickness.

Since  $d$  and  $\alpha$  are components of the Biot number

$$Bi = \frac{d\alpha}{2\lambda_{gl}},$$

where  $\lambda_{gl}$  is the thermal conductivity of glass, it is possible at the same time to introduce the notion of a guarantee Biot value:

$$Bi_g = \frac{d\alpha_g}{2\lambda_{gl}}.$$

For window glass with  $\lambda_{gl} \approx 0.878 \text{ W/(m} \cdot \text{K)}$

$$Bi_g = \frac{1.703}{2 \times 0.878} = 0.97 \approx 1.$$

On the other hand, the formula for estimating the heat transfer coefficient for preset design parameters of the dif-

fuser (Fig. 1) is known as well [3]:

$$\begin{aligned} \alpha &= 0.286 \frac{\lambda_a}{X} Re^{0.625}; \\ Re &= 6.63v \frac{DX\rho}{Z\mu}, \end{aligned} \quad (1)$$

where  $\lambda_a$  is the thermal conductivity coefficient of air;  $X$  is the nozzle spacing;  $v$  is the velocity of air flowing out of the nozzles;  $D$  is the cross-section diameter;  $Z$  is the distance from the nozzle exit to the surface cooled;  $\rho$  is the air density; and  $\mu$  is the coefficient of dynamic viscosity of air.

In the case of critical air flow

$$v = c = \sqrt{k \frac{p_{atm}}{\rho}}, \quad (2)$$

where  $c$  is the sound velocity in the ambient medium;  $k$  is the adiabatic index; and  $p_{atm}$  is the atmospheric pressure.

In this case the Reynolds number also takes a critical value:

$$Re_{cr} = 6.63c \frac{DX\rho}{Z\mu}, \quad (3)$$

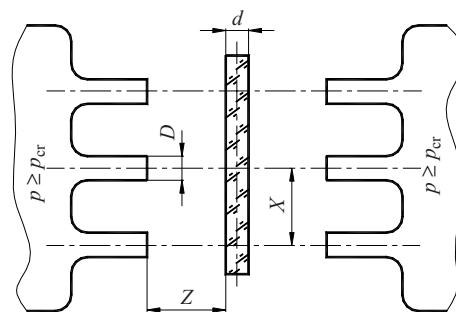
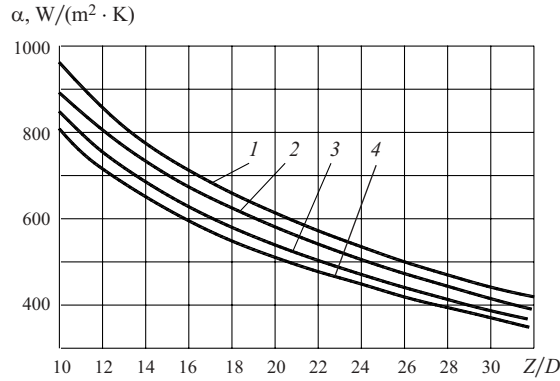


Fig. 1. Scheme of air-jet hardening of glass under a critical air flow.

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**Fig. 2.** Cooling capacity of chilling diffusers depending on their design parameters with  $X = 25$  (1), 30 (2), 35 (3), and 40 mm (4).

and the heat transfer coefficient after certain transformations of expressions (1) – (3) takes the following form:

$$\alpha = \alpha_{cr} = 0.933 \left[ \lambda_a (k p_{atm} \rho)^{0.312} \left( \frac{1}{m} \right)^{0.625} \right] \times \left[ \left( \frac{D}{Z} \right)^{0.625} \frac{1}{X^{0.375}} \right]. \quad (4)$$

The two groups of parameters in square brackets can be isolated in relationship (4). The first group consists only of the physical constants of the cooling air and all of them are known. The second group includes only the design parameters of the hardening diffusers.

Relationship (4) can be used in two ways.

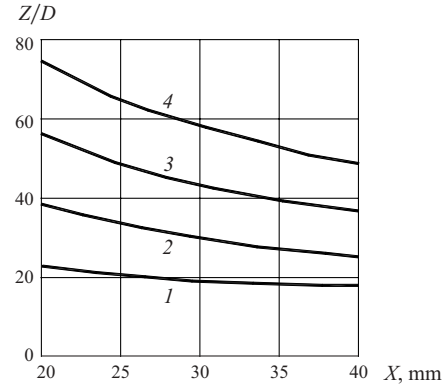
First, by a direct calculation it is possible to obtain a series of dependences of the cooling intensity of the diffuser design parameters (Fig. 2), showing that the level of  $\alpha = 800 - 1000 W/(m^2 \cdot K)$ , which is more typical of liquid hardening, is quite feasible for the critical conditions. In the central segment of the plot  $\alpha \approx 600 W/(m^2 \cdot K)$ , which is sufficient for hardening thin (3 mm) glass.

Second, the above relationship can be generalized by equating

$$\alpha_g = \alpha_{cr}$$

and resolving the obtained equation with respect to

$$\frac{Z}{D} = 0.295 \frac{d^{1.6}}{X^{0.6}} \left( \frac{\lambda_a}{\lambda_{gl}} \right)^{1.6} \frac{\sqrt{k p_{atm} \rho}}{\mu}. \quad (5)$$



**Fig. 3.** Relationship between the design parameters of diffusers in the case of guaranteed glass hardening at  $d = 3$  (1), 4 (2), 5 (3), and 6 mm (4).

By substituting the physical constants of air at a temperature of  $20^\circ C$  into relationship (5), we obtain

$$\frac{Z}{D} = 25,381 \frac{d^{1.6}}{X^{0.6}}, \quad (6)$$

i.e., a sufficiently rigid relationship between the glass thickness and the design parameters of diffusers is obtained with guaranteed hardening estimated based on the strength and the type of destruction of the hardened article.

The plots constructed in accordance with dependence (6) are shown in Fig. 3. It can be noted that rather large relative distances to the surface cooled are typically registered under the critical air flow conditions ( $Z/D = 20 - 70$ ), and in passing from 3-mm glass to 6-mm glass, a threefold increase in  $Z/D$  on the average is observed.

The obtained results were used in designing hardening diffusers with a critical air flow.

## REFERENCES

1. A. G. Shabanov, A. I. Shutov, and V. I. Potapov, "Aerodynamic characteristics and cooling capacity of air-jet devices for sheet glass hardening," *Steklo Keram.*, No. 1, 4 – 6 (1982).
2. A. I. Shutov and E. P. Sakulina, "The guaranteed heat transfer coefficient in glass hardening," *Steklo Keram.*, No. 6, 10 – 11 (1991).
3. A. I. Shutov, I. A. Novikov, and A. A. Chistyakov, "Cooling capacity of contemporary cooling diffusers," *Steklo Keram.*, No. 2, 10 – 11 (2000).